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Lepton-Flavor Violating Decays of the Z-boson in a Left-Right Supersymmetric Model

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Abstract

We study the one-loop supersymmetric contributions to lepton-flavor violating Z -boson decays in a fully left-right symmetric model. In addition to right-handed scalar neutrinos, the decays could receive important contributions from doubly-charged triplet Higgsinos which couple to leptons only. We find that the decay widths reach present experimental bounds and discuss mass constraints for the contributing supersymmetric partners.

1 Introduction

The quest for understanding beyond the Standard Model physics and its implications for the present and future colliders has relied heavily on extended gauge structures of the Standard Model. Among these Supersymmetric Grand Unfied Theories ($SUSYGUT's$) such as $SO(10)$ and $SU(5)$ have received significant attention, due to their correct prediction of the electroweak mixing angle [1]. These theories provide unfication of interactions at a higher scale than the ordinary $GUT's$, which prevents rapid proton decay. Another attractive feature of these models is the prediction of a small but non-vanishing neutrino mass. Indeed, anomalies measured in solar and atmospheric neutrino fluxes seem to lend support to the idea that neutrinos should have a small but nonvanishing mass. The most promising candidate for a mechanism to give the neutrino a mass is the see-saw model, which explains the smallness of the neutrino mass in terms of the large Majorana mass for a right-handed neutrino ν_R [2].

Phenomenologically, the introduction of three families for the right-handed neutrinos brings a new matrix for the Yukawa couplings in the lepton sector, similar to the one in the quark sector. A simultaneous diagonalization of both matrices is quite accidental and, as in the quark sector, the new leptonic Yukawa couplings cause lepton-flavour violation. This phenomenon could exist in a supersymmetric version of the Standard Model with the introduction of right-handed neutrinos [3]. It can also occur naturally in one of the $SUSY-GUT$ models. The simplest extension of the Minimal Supersymmetric Standard Model which would include right-handed neurinos naturally is the one based on the left-right symmetric extension of the Standard Model. We will investigate here lepton-flavor violating decays of the Z-boson in a fully left-right supersymmetric model .

The Left-Right Supersymmetric Model ($LRSUSY$) is an extension of the Minimal Supersymmetric Standard Model based on left-right symmetry. $LRSUSY$ shares some of the attractive properties of the $MSSM$, like providing a natural solution for the gauge hierarchy problem; and, in addition, $LRSUSY$ supresses naturally rapid proton decay, by disallowing terms in the Lagrangian that explicitly violate either baryon or lepton numbers [4].It gauges the only quantum number left ungauged, $B-L$. The $LRSUSY$ model shares some of the attractive features of the original left-right symmetric model [5], such as providing a possible explanation for the strength of CP violation. It could be viewed as a low-energy realization

of certain $SUSY-GUTs$, such as $SO(10)$ or $SU(5)$. So far there is no experimental evidence for the right-handed interactions predicted by the $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ theory, let alone by supersymmetry. Yet the foundation of $LRSUSY$ has so many attractive features that the model deserves some experimental and theoretical investigation. The next generation of linear colliders will provide an excellent opportunity for such a study. The theoretical and experimental challenge lies in finding distinctive features for the left-right supersymmetric model, which allow it to be distinguished from both the SUSY version of the Standard Model and from the non-supersymmetric version of the left-right theory [6]. Lepton-flavour violation decays are just the right type of such phenomena. The LRSUSY model provides a natural framework for large lepton flavor-violating effects through two mechanisms: on one hand it can give rise to a leptonic decay width of the Z-boson through both left-handed and right-handed scalar lepton mixing , on the other hand it contains lepton-flavor-blind higgsinos which couple to leptons only and enhance lepton-flavor violation.

Our paper is organized as follows: in Section 2, we describe the $LRSUSY$ model; in Section 3 we discuss the supersymmetric contributions (including both the $MSSM$ and the $LRSUSY$ contributions) to the decay rate $Z \to l_1 \bar{l}_2$. We will conclude in Section 4 with numerical estimates and discussion.

2 The Left-Right Supersymmetric Model

The $LRSUSY$ model, based on $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$, has matter doublets for both left- and right- handed fermions and the corresponding left- and right-handed scalar partners (sleptons and squarks) [6]. In the gauge sector, corresponding to $SU(2)_L$ and $SU(2)_R$, there are triplet gauge bosons $(W^{+,-}, W^0)_L$, $(W^{+,-}, W^0)_R$ and a singlet gauge boson V corresponding to $U(1)_{B-L}$, together with their superpartners. The Higgs sector of this model consists of two Higgs bi-doublets, $\Phi_u(\frac{1}{2}, \frac{1}{2}, 0)$ and $\Phi_d(\frac{1}{2}, \frac{1}{2}, 0)$, which are required to give masses to both the up and down quarks. In addition, the spontaneous symmetry breaking of the group $SU(2)_R \times U(1)_{B-L}$ to the hypercharge symmetry group $U(1)_Y$ is accomplished by introducing the Higgs triplet fields $\Delta_L(1, 0, 2)$ and $\Delta_R(0, 1, 2)$. The choice of the triplets (versus four doublets) is preferred because with this choice a large Majorana mass can be generated for the right-handed neutrino and a small one for the left-handed neutrino [5]. In addition to the triplets $\Delta_{L,R}$, the model must contain two additional triplets $\delta_L(1, 0, -2)$

and $\delta_R(0,1,-2)$, with quantum number $B-L=-2$ to insure cancellation of the anomalies that would otherwise occur in the fermionic sector. Given their strange quantum numbers, the δ_L and δ_R do not couple to any of the particles in the theory so their contribution is negligible for any phenomenological studies.

As in the standard model, in order to preserve $U(1)_{EM}$ gauge invariance, only the neutral Higgs fields aquire non-zero vacuum expectation values ($VEV's$). These values are:

$$< \Delta_L >= \begin{pmatrix} 0 & 0 \\ v_L & 0 \end{pmatrix}, < \Delta_R >= \begin{pmatrix} 0 & 0 \\ v_R & 0 \end{pmatrix} \text{ and } < \Phi >= \begin{pmatrix} \kappa & 0 \\ 0 & \kappa' e^{i\omega} \end{pmatrix}$$

$< \Phi >$ causes the mixing of W_L and W_R bosons with CP-violating phase ω. In order to simplify, we will take the $VEV's$ of the Higgs fields as: $< \Delta_L >= 0$ and

$$< \Delta_R >= \begin{pmatrix} 0 & 0 \\ v_R & 0 \end{pmatrix}, < \Phi_u >= \begin{pmatrix} \kappa_u & 0 \\ 0 & 0 \end{pmatrix} \text{ and } < \Phi_{\rm d} >= \begin{pmatrix} 0 & 0 \\ 0 & \kappa_d \end{pmatrix}$$

Choosing $v_L = \kappa' = 0$ satisfies the more loosely required hierarchy $v_R \gg max(\kappa, \kappa') \gg v_L$ and also the required cancellation of flavor-changing neutral currents. The Higgs fields aquire non-zero $VEV's$ to break both parity and $SU(2)_R$. In the first stage of breaking the right-handed gauge bosons W_R and Z_R aquire masses proportional to v_R and become much heavier than the usual (left-handed) neutral gauge bosons W_L and Z_L, which pick up masses proportional to κ_u and κ_d at the second stage of breaking. [4]

The supersymmetric sector of the model, while preserving left-right symmetry, has four singly-charged charginos (corresponding to $\tilde{\lambda}_L, \tilde{\lambda}_R, \tilde{\phi}_u$, and $\tilde{\phi}_d$), in addition to $\tilde{\Delta}_L^-$, $\tilde{\Delta}_R^-$, $\tilde{\delta}_L^-$ and $\tilde{\delta}_R^-$. The model also has eleven neutralinos, corresponding to $\tilde{\lambda}_Z$, $\tilde{\lambda}_{Z\prime}$, $\tilde{\lambda}_V$, $\tilde{\phi}^0_{1u}$,$\tilde{\phi}^0_{2u}$, $\tilde{\phi}^0_{1d}$, $\tilde{\phi}^0_{2d}$, $\tilde{\Delta}^0_L$, $\tilde{\Delta}^0_R$ $\tilde{\delta}^0_L$, and $\tilde{\delta}^0_R$. It has been shown that in the scalar sector, the left-triplet Δ_L couplings can be neglected in phenomenological analyses of muon and tau decays [3]. Also Δ_L is not necessary for symmetry breaking [7]; it is introduced only for preserving left-right symmetry. We will therefore neglect the couplings of Δ_L in the fermionic sector.

The doubly charged Δ_R^{--} is however very important: it carries quantum number $B-L$ of 2 and couples only to leptons, therefore breaking lepton-quark universality. It and its supersymmetric partner could, as will be seen in the next section, play an important role in flavour-violating leptonic decays.

In the scalar matter sector, the $LRSUSY$ contains two left-handed and two right-handed scalar fermions as partners of the ordinary leptons and quarks, which themselves come in

left- and right-handed doublets. In general the left- and right-handed scalar leptons will mix together. Some of the effects of this mixings, such as enhancement of the anomalous magnetic moment of the muon, have been discussed elsewhere [4]. Only global lepton-family-number violation would prevent $\tilde{e}$, $\tilde{\mu}$ and $\tilde{\tau}$ to mix arbitrarily. Permitting this mixing to occur, we could expect small effects to occur in the non-supersymmetric sector, such as radiative muon or tau decays, in addition to other nonstandard effects such as massive neutrino oscillations and violation of lepton number itself. But, in general, allowing for the mixing, we have six charged-scalar lepton states (involving 15 real angles and 10 complex phases) and six scalar neutrinos (also involving 15 real angles and 10 complex phases). In order to reduce the (large) number of parameters we shall assume in what folows that only two generations of scalar leptons (the heaviest) mix significantly [8] . The mixings are as follows: $\tilde{\mu}_{L,R}$ and $\tilde{\tau}_{L,R}$ with angle $\theta_{L,R}$; $\tilde{\nu}_{\mu_{L,R}}$ and $\tilde{\nu}_{\tau_{L,R}}$ with angle $\alpha_{L,R}$; so that, for example:

$$\tilde{l}_{L_1} = \tilde{\mu}_L cos\theta_L + \tilde{\tau}_L sin\theta_L$$

$$\tilde{l}_{L_2} = -\tilde{\mu}_L sin\theta_L + \tilde{\tau}_L cos\theta_L$$

and similarly for $\tilde{l}_{R_{1,2}}$ and $\tilde{\mu}_{L_{1,2}}$ and $\tilde{\mu}_{R_{1,2}}$. These states are the physical mass eigenstates.

Next we consider the implications of the above-mixing in the $LRSUSY$ in lepton-flavor violating decays of the Z_L boson.

3 Lepton Number Violating Decays

There are two types of contributions to the lepton-number violating decays: one coming from the non-SUSY sector of the left-right model, the other type coming from the SUSY sector, through the contributions of supersymmetric partners. To keep the parameters to a minimum, we choose to evaluate analytically the contribution to amplitude for the decay $Z \rightarrow l_1 \bar{l}_2$ due to the mixing of scalar leptons and scalar neutrinos and due to the charginos and neutralinos in the model. We note that the mass parameters which determine the contribution in the SUSY sector are independent (in broken supersymmetry) of the ones in the non-SUSY sector. For completeness, we refer the reader to [3].

In general , the branching ratio for this process can be written as:

$$B(Z \rightarrow \bar{l}_1 l_2 + l_1 \bar{l}_2) = \frac{\alpha_w^3}{48\pi cos_w^2} \frac{M_Z}{\Gamma_Z} [|\Gamma^L_{l_1 l_2}|^2 + |\Gamma^R_{l_1 l_2}|^2],$$

where the nonoblique functions $\Gamma^L_{l_1 l_2}$ and $\Gamma^R_{l_1 l_2}$ depend on the $V-A$ or $V+A$ character of the theory. Such a branching ratio is restricted by LEP to be *e.g.* $B(Z \to e\tau) \leq 10^{-5}$ [11].

We assume that the leptonic masses are small (and therefore negligible) compared to at least one mass of a supersymmetric particle in the process.

There are 9 relevant diagrams that contribute to $\Gamma^L_{l_1 \bar{l}_2}$ and $\Gamma^R_{l_1 \bar{l}_2}$ and they are listed in Fig. 1. The contributions from the individual graphs are listed below. First , the left-handed contributions which are similar, although not identical, to the ones in the $MSSM$ [8] :

$$\begin{aligned}\Gamma^L_{l_1\bar{l}_2}(A) &= \frac{-1}{2}\frac{ie^3}{32\pi^2\sin^2\theta_w\sin 2\theta_w}\sin 2\theta_L[\sum_{i=1}^{4}(|\tan\theta_w N_{i1}+N_{i2}|^2)\cos 2\theta_w\tilde{\lambda}_{l_{L_1}} \\ &\quad C_{24}(\tilde{\lambda}^0_i,\tilde{\lambda}_{l_{L_1}},\tilde{\lambda}_{l_{L_1}})] \qquad (1)\end{aligned}$$

$$\Gamma^L_{l_1\bar{l}_2}(B) = \frac{ie^3}{32\pi^2\sin^2\theta_w\sin 2\theta_w}\sin 2\alpha_L\sum_{i=1}^{4}(|V_{i1}|^2)\tilde{\lambda}_{\nu_{L_1}}C_{24}(\tilde{\lambda}^-_i,\tilde{\lambda}_{\nu_{L_1}},\tilde{\lambda}\nu_{L_1}) \qquad (2)$$

$$\begin{aligned}\Gamma^L_{l_1\bar{l}_2}(D) &= \frac{ie^3}{32\pi^2\sin^2\theta_w\sin 2\theta_w}\sin 2\theta_L \\ &\quad [\sum_{i=1}^{4}\sum_{j=1}^{4}(\tan\theta_w N^*_{i1}+N^*_{i2})(\tan\theta_w N_{j1}+N_{j2}) \\ &\quad O^{L''}_{ij}(2C_{24}(\tilde{\lambda}_{l_{L_1}},\tilde{\lambda}^0_i,\tilde{\lambda}^0_j)-1/2+\lambda_z(C_{23}(\tilde{\lambda}_{l_{L_1}},\tilde{\lambda}^0_i,\tilde{\lambda}^0_j) \\ &\quad -C_{22}(\tilde{\lambda}_{l_{L_1}},\tilde{\lambda}^0_i,\tilde{\lambda}^0_j))-O^{R''}_{ij}\sqrt{\tilde{\lambda}^0_i\tilde{\lambda}^0_j}C_0(\tilde{\lambda}_{l_{L_1}},\tilde{\lambda}^0_i,\tilde{\lambda}^0_j)] \qquad (3)\end{aligned}$$

$$\begin{aligned}\Gamma^L_{l_1\bar{l}_2}(E) &= \frac{2ie^3}{32\pi^2\sin^2\theta_w\sin 2\theta_w}\sin 2\alpha_L[\sum_{i=1}^{4}\sum_{j=1}^{4}(V^*_{i1}V_{j1}) \\ &\quad O^{L'}_{ij}(2C_{24}(\tilde{\lambda}_{\nu_{L_1}},\tilde{\lambda}^-_i,\tilde{\lambda}^+_j)-1/2+\lambda_z(C_{23}(\tilde{\lambda}_{\nu_{L_1}},\tilde{\lambda}^-_i,\tilde{\lambda}^+_j) \\ &\quad -C_{22}(\tilde{\lambda}_{\nu_{L_1}},\tilde{\lambda}^-_i,\tilde{\lambda}^+_j))-O^{R'}_{ij}\sqrt{\tilde{\lambda}^-_i\tilde{\lambda}^+_j}C_0(\tilde{\lambda}_{\nu_{L_1}},\tilde{\lambda}^-_i,\tilde{\lambda}^+_j)] \qquad (4)\end{aligned}$$

$$\begin{aligned}\Gamma^L_{l_1\bar{l}_2}(G) &= \frac{1}{2}\frac{ie^3}{32\pi^2\sin^2\theta_w\sin 2\theta_w}\sin 2\theta_L\sum_{i=1}^{4}(|\tan\theta_w N_{i1}+N_{i2}|^2)\cos 2\theta_w \\ &\quad B_1(0,\tilde{\lambda}^0_i,\tilde{\lambda}_{l_{L_1}}) \qquad (5)\end{aligned}$$

$$\Gamma^L_{l_1\bar{l}_2}(H) = \frac{1}{2}\frac{ie^3}{32\pi^2\sin^2\theta_w\sin 2\theta_w}\sin 2\alpha_L\sum_{i=1}^{4}\tilde{\lambda}^-_i(|V_{i1}|^2)B_1(0,\tilde{\lambda}^-_i,\tilde{\lambda}_{\nu_{R_1}}) \qquad (6)$$

where $\lambda_n = m_n^2/M_{W_L}^2$, the functions $C_{ij}(\lambda_i, \lambda_j, \lambda_k)$ are the three-point functions , and $B_1(0, \lambda_i, \lambda_j)$ is a two-point function associated with the self-energy graphs. We follow the notation and conventions of Ref. [9], to which we refer the reader for further details. In $LRSUSY$ mixing of right-handed scalar leptons as well as gauginos induce a nonuniversal coupling of the Z_L , Γ^R as shown in Fig. 1. The contributions are as given below:

$$\begin{aligned}\Gamma^R_{l_1\bar{l}_2}(A) &= 2\frac{ie^3}{32\pi^2\sin^2\theta_w\sin 2\theta_w}\sin 2\theta_R\sum_{i=1}^{4}(|\tan\theta_w N_{i1}|^2)2sin^2\theta_w\tilde{\lambda}_{l_{R_1}} \\ &\quad C_{24}(\tilde{\lambda}_i^0, \tilde{\lambda}_{l_{R_1}}, \tilde{\lambda}_{l_{R_1}})\end{aligned} \tag{7}$$

$$\Gamma^R_{l_1\bar{l}_2}(B) = \frac{ie^3}{32\pi^2\sin^2\theta_w\sin 2\theta_w}\sin 2\alpha_R\sum_{i=1}^{4}(|V_{i2}|^2)\tilde{\lambda}_{\nu_{R_1}}C_{24}(\tilde{\lambda}_i^-, \tilde{\lambda}_{\nu_{R_1}}, \tilde{\lambda}_{\nu_{R_1}}) \tag{8}$$

$$\Gamma^R_{l_1\bar{l}_2}(C) = \frac{ie^3}{32\pi^2\sin^2\theta_w\sin 2\theta_w}\sin 2\theta_R\tan^2\theta_k\sin^2\theta_w\tilde{\lambda}_{l_{R_1}}C_{24}(\tilde{\lambda}_\delta^{--}, \tilde{\lambda}_{l_{R_1}}, \tilde{\lambda}_{l_{R_1}}) \tag{9}$$

$$\begin{aligned}\Gamma^R_{l_1\bar{l}_2}(D) &= \frac{ie^3}{32\pi^2\sin^2\theta_w\sin 2\theta_w}\sin 2\theta_L[\sum_{i=1}^{4}\sum_{j=1}^{4}(2\tan\theta_w N_{i1}^*)(2\tan\theta_w N_{j1})O_{ij}^{R"} \\ &\quad (2C_{24}(\tilde{\lambda}_{l_{R_1}}, \tilde{\lambda}_i^0, \tilde{\lambda}_j^0) - 1/2 + \lambda_z(C_{23}(\tilde{\lambda}_{l_{R_1}}, \tilde{\lambda}_i^0, \tilde{\lambda}_j^0) \\ &\quad -C_{22}(\tilde{\lambda}_{l_{R_1}}, \tilde{\lambda}_i^0, \tilde{\lambda}_j^0)) - O_{ij}^{L"}\sqrt{\tilde{\lambda}_i^0\tilde{\lambda}_j^0}C_0(\tilde{\lambda}_{l_{R_1}}, \tilde{\lambda}_i^0, \tilde{\lambda}_j^0)]\end{aligned} \tag{10}$$

$$\begin{aligned}\Gamma^R_{l_1\bar{l}_2}(E) &= \frac{2ie^3}{32\pi^2\sin^2\theta_w\sin 2\theta_w}\sin 2\alpha_R[\sum_{i=1}^{4}\sum_{j=1}^{4}(V_{i2}^*V_{j2})O_{ij}^{R'} \\ &\quad (2C_{24}(\tilde{\lambda}_{\nu_{R_1}}, \tilde{\lambda}_i^-, \tilde{\lambda}_j^+) - 1/2 + \lambda_z(C_{23}(\tilde{\lambda}_{\nu_{R_1}}, \tilde{\lambda}_i^-, \tilde{\lambda}_j^+) \\ &\quad -C_{22}(\tilde{\lambda}_{\nu_{R_1}}, \tilde{\lambda}_i^-, \tilde{\lambda}_j^+)) - O_{ij}^{L'}\sqrt{\tilde{\lambda}_i^-\tilde{\lambda}_j^+}C_0(\tilde{\lambda}_{\nu_{R_1}}, \tilde{\lambda}_i^-, \tilde{\lambda}_j^+)]\end{aligned} \tag{11}$$

$$\begin{aligned}\Gamma^R_{l_1\bar{l}_2}(F) &= \frac{1}{2}\frac{ie^3}{32\pi^2\sin^2\theta_w\sin 2\theta_w}\sin 2\theta_R\sin^2\theta_w\tan^2\theta_k\tilde{\lambda}_\delta \\ &\quad [2C_{24}(\tilde{\lambda}_{\nu_{R_1}}, \tilde{\lambda}_\delta, \tilde{\lambda}_\delta) - 1/2 + \\ &\quad \lambda_z(C_{23}(\tilde{\lambda}_{\nu_{R_1}}, \tilde{\lambda}_\delta, \tilde{\lambda}_\delta) - C_{22}(\tilde{\lambda}_{\nu_{R_1}}, \tilde{\lambda}_\delta, \tilde{\lambda}_\delta))]\end{aligned} \tag{12}$$

$$\begin{aligned}\Gamma^R_{l_1\bar{l}_2}(G) &= 2\frac{ie^3}{32\pi^2\sin^2\theta_w\sin 2\theta_w}\sin 2\theta_R\sum_{i=1}^{4}\tilde{\lambda}_i^0(|\tan\theta_w N_{i1}|^2)2\sin^2\theta_w \\ &\quad B_1(0, \tilde{\lambda}_i^0, \tilde{\lambda}_{l_{R_1}})\end{aligned} \tag{13}$$

$$\Gamma^R_{l_1\bar{l}_2}(H) = 4\frac{ie^3}{32\pi^2\sin^2\theta_w\sin 2\theta_w}\sin 2\alpha_R\sum_{i=1}^{4}\tilde{\lambda}_i^-(|V_{i2}|^2)B_1(0, \tilde{\lambda}_i^-, \tilde{\lambda}_{\nu_{R_1}}) \tag{14}$$

$$\Gamma^R_{l_1\bar{l}_2}(I) = \frac{-1}{4}\frac{ie^3}{32\pi^2\sin^2\theta_w\sin 2\theta_w}\tan^2\theta_k \sin 2\theta_R \tilde{\lambda}_\delta B_1(0,\tilde{\lambda}_\delta,\tilde{\lambda}_\delta) \tag{15}$$

Here O_{ij} and N_{ij} arise from neutralino mixing and coupling at the vertices; $O\prime_{ij}$ and V_{ij} , U_{ij} arise from chargino mixing at the vertices. The expressions for these matrix elemens are rather lengthy; they have been calculated previously, in a work dealing in detail with chargino and neutralino masses, and are listed in [10].

4 Numerical Results and Discussion

As seen in the previous section, the left-right supersymmetric contributions to the branching ratio $BR(Z \to l_1\bar{l}_2)$ depend on a plethora of parameters: chargino and neutralino masses and mixing matrix elements, as well as sleptons and sneutrino masses and mixing angles. An exact evaluation of this cross section would require fixing all the parameters: clearly an impossible task. We attempt to estimate the possible values of the branching ratio in order to get an idea for the range of parameters and then compare the result with current experimental data: for example with the branching ratio $BR(Z \to \tau^\pm e^\mp) \leq 1.3 \times 10^{-5}$. Similar results are obtained for $BR(Z \to \mu^\pm\tau^\mp) \leq 1. \times 10^{-5}$ and $BR(Z \to e^\pm\tau^\mp) \leq 6 \times 10^{-6}$ [11].

In particular, we would like to get an estimate for the case in which this branching ratio is large, perhaps close to the experimental bound. We shall make several simpifying assumptions with this in mind.

First, from the expressions for the matrix elements, it can be seen that the largest cross section occurs when the mass splittings between $\tilde{l}_{L_{1,2}}$, $\tilde{l}_{R_{1,2}}$, $\tilde{\nu}_{L_{1,2}}$ and $\tilde{\nu}_{R_{1,2}}$ are large. We shall therefore assume that the scalar leptons and neutrinos mix maximally, that is, $\theta_L = \theta_R = \alpha_L = \alpha_R = \pi/4$. Also we assume maximal mass splitting for the scalar leptons and sneutrinos, that is, we assume that $\tilde{\nu}_{L_1}$, $\tilde{\nu}_{R_1}$, $\tilde{l}_{L_1}$ and $\tilde{l}_{R_1}$ are relatively light, but $\tilde{\nu}_{L_2}$, $\tilde{\nu}_{R_2}$, $\tilde{l}_{L_2}$ and $\tilde{l}_{R_2}$ are very heavy , and therefore decouple.

Second, the cross section will be smallest for the lightest allowable supersymmetric partners. As the mass of any particle becomes large, the contributions from the subprocesses involving that particle become negligibly small.

Since leptonic masses are taken to be small compared to that of their supersymmetric partners, the terms proportional to lepton masses arising from the higgsino component of a vertex (either chargino or neutralino) can be ignored.

We base our estimates for chargino and neutralino masses and mixing matrices on previous work done on the subject. For completness, we refer the reader to [10]. It suffices to mention here that both chargino and neutralino masses, as well as their mixing matrices depend on the following parameters :M_L , the left-handed gaugino mass parameter, M_R,the right-handed gaugino mass parameter, μ, the higgsino mass parameter, and $\tan\theta_k = \kappa_u/\kappa_d$. In addition the cross section will depend on the mass of the Δ_L^{--} which is otherwise unrestricted.

We shall examine the cross section as a function of all the masses, which is more illuminating than a function of M_L, M_R, μ and $\tan\theta_k$. For simplification we will take $\tan\theta_k = 2$ in all our considerations.

To get a feeling for the size of the supersymmetric contributions we first choose an "unbroken supersymmetry" limit, in which the first two neutralinos are degenerate in mass with the photon and Z_L boson, the first two charginos are degenerate in mass with the W_L boson , all the "1" scalar leptons and scalar neurinos have the same mass , and all the other supersymmetric particles are much heavier and decouple. The only supersymmetry breaking terms are explicit mass terms for the scalar leptons and neutrinos. The results are shown in Fig. 2. It can bee seen that for light scalar partners in this idealized scenario, the branching ratio $Z \to l_1\bar{l}_2$ can reach values close to the experimental limits.

After getting a rough estimate for the size of the branching ratio, we analyse the effects of varying one of the masses while keeping the others constant. We do this to investigate the dependence of the branching ratio on the chargino and neutralino masses , as well as scalar leptons and scalar neutrino masses. We restrict our analysis to the light mass region of the supersymmetric particles in the hope that effects measured there could be noticeable.

In Fig. 3 we plot the dependence of the branching ratio on the chargino and neutralino masses. It is impossible to treat separately the chargino and neutralino masses, since as explained above, they depend on the same set of parameters. To simplify, we consider the influence of the lightest two charginos. Taking $m_{\tilde{\chi}_1^\pm}$ to be the variable, we see that as expected, the cross section decreases with increasing $m_{\tilde{\chi}_1^\pm}$ and could reach 3×10^{-5} for all masses being at their lowest experimental bound. (We could have chosen in much the same way to plot the dependence of the branching ratio on the lightest neutralino mass $m_{\tilde{\chi}_1^0}$). In many models the first neutralino (the photino) is assumed to be the LSP and its mass is restricted to be ≥ 25 GeV; such values can be obtained in the $LRSUSY$ model and are

consistent with Fig. 3. The cross section again can reach values close to the experimental bounds.

Fig. 4 shows the dependence of the cross section on the scalar neutrino masses. (Assuming the left and right scalar neutrinos to be degenerate in mass). We also take the left and right scalar leptons to be degenerate in mass around 100 GeV. This is for the purpose of increasing the total cross section, since the right-handed sleptons contribute only to $\Gamma^R_{l_1\bar{l}_2}$ and the left-handed ones only to $\Gamma^L_{l_1\bar{l}_2}$. Again , these are idealized assumptions, the cross section varies weakly with these masses, but it can reach values near the experimental bounds.

The most interesing dependence is perhaps the one on the mass of the doubly-charged $\tilde{\Delta}_R^{--}$ higgsino. This chargino does not mix with other ones because of its charge, and it can significantly increase the branching ratio $BR(Z \to l_1\bar{l}_2)$ through scalar-leptons-scalar-leptons loops, as well as through the self energy graphs. The dependence of the cross section on the mass of the $\tilde{\Delta}_R^{--}$ is shown in Fig. 5. The branching ratio can exceed the experimental limits unless the mass of the $\tilde{\Delta}_R^{--}$ is larger than 120 GeV. This seems to be the only definite restriction of this analysis. It seems to persist even when $\tan\theta_k$ is varied(in the region 2 to 5). When $\tan\theta_k$ varies, the chargino and neutralino masses become large and their contribution smaller, but this is offset by an increase in the contribution from the $\tilde{\Delta}_R^{--}$.

In conclusion , we have shown that the Left-Right Supersymmetric Model, unlike the $MSSM$, can give significant contributions to lepton-number-violating decays of the Z_L-boson, especially for light (near experimental bounds) charginos and neutralinos. It seems possible to observe such a decay rate at SLC, even if the only contribution to these decays arises from slepton and sneutrino mixing. The present limits on the masses and leptonic decays seem to restrict the mass of the doubly-charged higgsino to at least 120 GeV.

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6 List of Figures

Figure 1 : Feynman graphs contribuing to the effective nonoblique $Zl_1\bar{l_2}$ coupling in $LRSUSY$.

Figure 2 : Branching Ratio $B(Z \to l_1\bar{l_2})$ in the "supersymmetry" limit. Here we vary all slepton and sneutrino masses (assumed to be equal), while keeping the chargino and neutralino masses at their $SUSY$ limit : $m_{\tilde{\chi}_1^0} = m_{\tilde{\gamma}} = 0$, $m_{\tilde{\chi}_2^0} = m_{\tilde{Z}_L} = m_Z$, $m_{\tilde{\chi}_1^\pm} = m_{\tilde{\chi}_2^\pm} = m_{\tilde{W}_L} = m_{W_L}$, all the other superpartners decouple. As defined in the text, $\lambda_n = m_n^2/M_{W_L}^2$.

Figure 3 : Branching Ratio $B(Z \to l_1\bar{l_2})$ as a function of the lightest chargino mass $m_{\tilde{\chi}_1^\pm}$, showing the dependence of the cross section on the chargino-neutralino mass parameters. Here $\lambda_{\tilde{\chi}_1^\pm} = m_{\tilde{\chi}_1^\pm}^2/M_{W_L}^2$. A similar graph could be obtained if one plotted the branching ratio as a function of the lightest neutralino mass. Here the scalar partners, the slepton and the sneutrino are assumed to have masses close to the experimental bounds: $m_{\tilde{l}} = 100\ GeV$ and $m_{\tilde{\nu}} = 45\ GeV$.

Figure 4 : Branching Ratio $BR(Z \to l_1\bar{l_2})$ as a function of the sneutrino mass $m_{\tilde{\nu}}$. Here all the chargino and neutralino have $SUSY$ limit masses: $m_{\tilde{\chi}_1^0} = m_{\tilde{\gamma}} = 0$, $m_{\tilde{\chi}_2^0} = m_{\tilde{Z}_L} = m_Z$, $m_{\tilde{\chi}_1^\pm} = m_{\tilde{\chi}_2^\pm} = m_{\tilde{W}_L} = m_{W_L}$, all the other superpartners decouple. The slepton mass is near the lowest experimental bound : $m_{\tilde{l}} = 100\ GeV$.

Figure 5 : Branching Ratio $B(Z \to l_1\bar{l_2})$ as a function of the doubly charged higssino , $\tilde{\Delta}_L^{++}$ mass . Here all the chargino and neutralino have $SUSY$ limit masses: $m_{\tilde{\chi}_1^0} = m_{\tilde{\gamma}} = 0$, $m_{\tilde{\chi}_2^0} = m_{\tilde{Z}_L} = m_Z$, $m_{\tilde{\chi}_1^\pm} = m_{\tilde{\chi}_2^\pm} = m_{\tilde{W}_L} = m_{W_L}$, all the other superpartners decouple. Here the slepton and the sneutrino are assumed to have masses close to the experimental bounds: $m_{\tilde{l}} = 100\ GeV$ and $m_{\tilde{\nu}} = 45\ GeV$.